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Extrinsic and intrinsic veins of the equine hoof wall

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INTRODUCTION

The growing popularity and economic importance of the domestic horse has made it essential that detailed information be gained about this species if husbandry procedures are to be effective. Knowledge about the locomotory system of the horse is particularly essential since effective performance is the *raison d'être* of this species. 'No hoof, no horse' has been the common slogan for centuries, yet many of the regulatory mechanisms which control growth and influence function of this important structure are not understood. It has been suggested that the hoof vascular system is very important in normal functions and in pathological processes affecting the hoof.

The hoof is believed to have preferential blood supplies to the proliferating areas and weight-bearing areas, but very few previous works have reported the organisation of blood vessels intrinsic to the hoof.

The normal function of the equine hoof can be disrupted by the change in its blood flow, subsequent to laceration, puncture wounds, sand cracks, fractures of the third phalanx, or laminitis. The characteristics and magnitude of these problems are not completely understood due to lack of information about the normal blood vascular system. For example, the decrease in the regional blood flow through the dermal lamellae in laminitis is believed to be related to the redirection of blood through arteriovenous (AV) shunts (Coffman & Garner, 1972; Hood *et al.* 1978), although the existence of such shunts has not been proven.

Finally, knowledge of the anatomy of blood vessels to the hoof and within the hoof is a prerequisite for any kind of surgical operation on the hoof.

The large calibre gross extrinsic and intrinsic* arteries of the hoof have been described by many investigators (Krüger, 1934; Schummer, 1951; de Vos, 1964; Ghoshal & Getty, 1968; Wintzer & Schlarmann, 1971; Hertsch, 1973; Pohlmeyer, 1979). The venous system is not as well understood. Gurlt was the first to describe the gross extrinsic venous drainage of the horse hoof and Storch (1894) was the first to prepare a corrosion cast of large calibre extrinsic and intrinsic veins of the hoof (Krüger, 1934). The extrinsic venous drainage has also been described by other investigators (Krüger, 1934; Schummer, 1951; Ghoshal, Koch & Popesko, 1981). The only attempts made to describe the intrinsic venous systems within the hoof were by Krüger and Schummer.

Recently it has been suggested that the venous system of the hoof is very important in understanding normal function and pathological conditions and may be particularly important in pathological conditions such as laminitis (Robinson, Dabney & Weidner, 1975; Eyre, Elmes & Strickland, 1979; Eyre & Elmes, 1980; Roberts,

* Extrinsic: vessels coming from or originating outside the hoof. Intrinsic: vessels originating within the hoof.

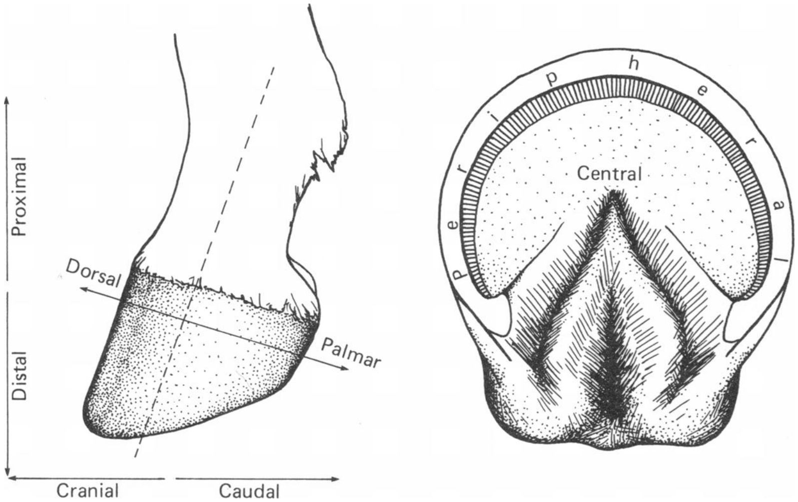

Fig. 1. Illustration showing some of the directional terminology used in this paper. Proximal: A term indicating relative position closer to the body. Distal: A term indicating relative position closer to the ground. Dorsal: A term indicating relative position closer to the upper or frontal surface of the digit. It relates specifically to a plane positioned at right angle to the long axis of the digit. Palmar: A term indicating relative position closer to the lower or back surface of the digit. It relates specifically to a plane positioned at right angle to the long axis of the digit. Cranial: A term indicating relative position closer to the head along the median plane of the digit. This differs from the term 'dorsal'. Caudal: A term indicating relative position closer to the tail along the median plane of the digit. This differs from the term 'palmar'. The term caudal and cranial are usually used to denote the position and orientation of structures proximal to the carpus. Axial: A term indicating relative position closer to the sagittal mid-line plane of the digit. Abaxial: A term indicating relative position away from the sagittal mid-line plane of the digit.

Ochoa & Haynes, 1980). The present work was undertaken to study the venous drainage of the equine hoof, specifically, the extrinsic and intrinsic veins of the forelimb hooves of clinically normal horses.

MATERIALS AND METHODS

Forty four pairs of clinically normal forelimb hooves from adult horses were used for this study. Five pairs of hooves were used for gross dissection, six pairs for histological preparation and 33 pairs for corrosion cast preparation.

The complex arrangement of the blood vascular system within the equine hoof necessitates a precise definition of terms used to describe the spatial orientation of these vessels. This terminology is defined and illustrated in Figure 1.

Preparation of corrosion casts

Within 1 hour of death of each animal, the hoof was removed by disarticulation of the forelimb at the metacarpophalangeal (fetlock) joint. Twenty eight of the 44 pairs of hooves studied were frozen prior to further preparation. All hooves were then processed in the following manner:

A teat cannula was inserted into one or both proper digital veins just distal to the fetlock joint. Two ligatures were tied around the veins and teat cannula to prevent the backflow of solution. The solutions were injected by hand using a 20 cc syringe. Retrograde perfusion was also done in a similar way by inserting a teat cannula into

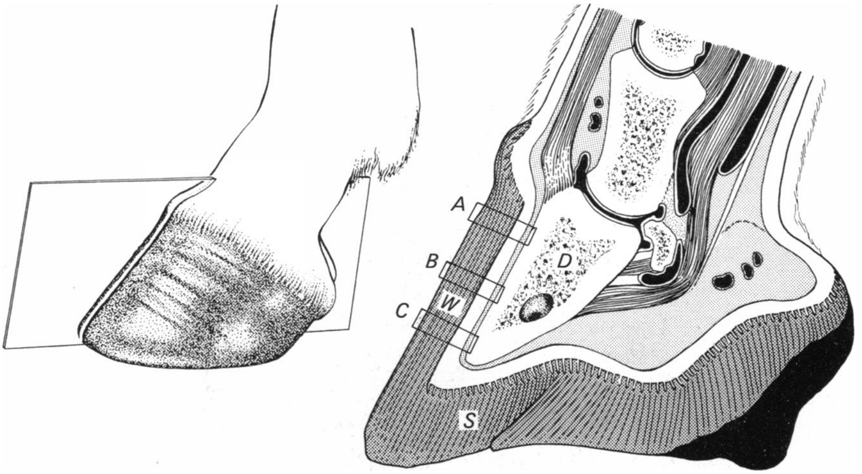

Fig. 2. Schematic illustration of sagittal section of the horse hoof. Rectangles labelled *A*, *B*, *C* are approximate areas from which tissues were taken for histological preparation. *D*, distal phalanx; *S*, sole; *W*, wall.

one or both proper digital arteries. Five hundred millilitres of warm, normal saline were first perfused through each hoof to relax the smooth muscle of the vascular bed. Methyl methacrylate plastic was then injected. A point was reached when there was substantial back pressure and when no more plastic could be injected. The teat cannula was then taken out of the vein and the vessel was blocked by using a haemostat to prevent the outflow of plastic.

After injecting the plastic the hooves were kept at room temperature for at least 4–6 hours to allow for polymerization of the methyl methacrylate. The hooves were then immersed in a saturated solution of sodium hydroxide to dissolve all the soft tissue and bones. The process of dissolving the soft tissue and bones required between 20 and 50 days.

Three pairs of hooves were injected with methyl methacrylate and two pairs of hooves with latex. These were dissected grossly to observe the relative position of the vessels to other structures of the hoof.

Preparation for histology

Within 1 hour of death of each animal, the front limb was disarticulated at the metacarpophalangeal (fetlock) joint and each hoof was perfused with normal saline and then with fixative (Bouin's solution). The hooves were then cut, using a band saw, into vertical columns, and a column from the toe, quarter and heel areas was sampled. Sampling sites from each column are shown in Figure 2.

Remnants of the third phalanx remaining with the sample were decalcified with 5% aqueous nitric acid (McManus & Mowry, 1965).

All tissue was trimmed off except that between the innermost portion of the stratum medium and the outer portion of bone. The tissue was processed and embedded in paraffin. Five micron sections were cut. The sections were then stained with Harris' haematoxylin and eosin (McManus & Mowry, 1965) or Masson's trichrome (Lillie, 1954).

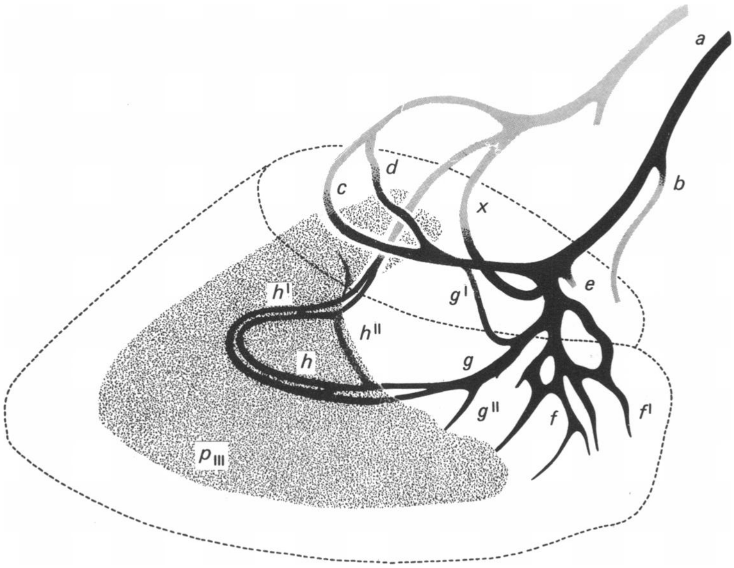

Fig. 3. Schematic diagram of the veins of the horse hoof showing, primarily, deeply situated veins. *a*, proper digital vein; *b*, caudal hoof vein; *c*, coronary vein; *d*, subcoronary vein; *e*, independent superficial vein; *f*, inner venous plexus; f^{I}, proximal branch of the inner venous plexus which contributed to paracuneal vein; *g*, terminal vein; g^{I}, dorsal tributary of terminal vein; g^{II}, ventral tributary of terminal vein; *h*, axial parallel vein; h^{I}, abaxial parallel vein; h^{II}, anastomosis between axial parallel veins; *x*, caudal anastomosis between proper digital veins; P_{III}, distal phalanx.

RESULTS

The medial and lateral proper digital veins (*V. digitalis* (*palmaris propria III*) *medialis* and *V. digitalis* (*palmaris propria III*) *lateralis*, respectively) (Figs. 3, 4, 6, 7, *a*) drain all the venous blood from the hoof. Other veins of the hoof can be divided into two groups: (1) *extrinsic*: those veins coming from or originating outside the hoof; and (2) *intrinsic*: those veins originating within the hoof. This oversimplified classification does not apply to every vein described in this work, but it does allow subdivision of the results into acceptably understandable units.

Extrinsic veins

The extrinsic veins of the hoof have been divided into two groups according to their location:

(A) *Deep veins* were those situated more interiorly, which related directly to structures such as the distal phalanx, distal sesamoid bone, hoof cartilage and the digital cushion.

(B) *Superficial veins* were those directly associated with the epidermis of the hoof (i.e. present within the dermis of the coronary band, wall, sole, frog and bulbar region).

(A) *Deep veins*

Two parallel veins were located within the semilunar canal of the distal phalanx: the vein that was closer to the mid-sagittal line was the axial parallel vein (Fig. 3, *h*) and the more peripherally located vein was the abaxial parallel vein (Fig. 3, h^{I}). These veins drained the deep venous network of the distal phalanx. Within the semi-

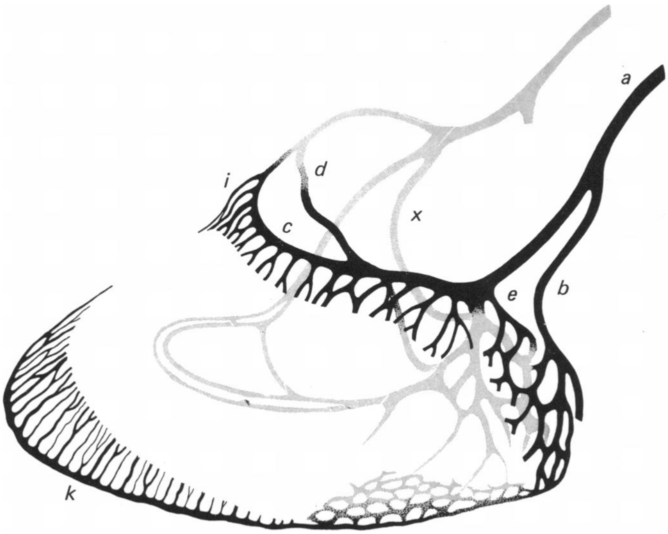

Fig. 4. Schematic diagram of the superficial veins of the horse hoof. *a*, proper digital vein; *b*, caudal hoof vein; *c*, coronary vein; *d*, subcoronary vein; *e*, independent superficial vein; *i*, long collecting vein; *k*, circumflex vein; *x*, caudal anastomosis between the proper digital veins.

lunar canal there were several anastomoses between the parallel veins. Both veins emerged through the solar foramen and, at the caudal border of the distal phalanx, the axial parallel vein sent a horizontal branch to form an anastomosis with a similar branch of the opposite side (Figs. 3, 5, h^{II}). This anastomosis received tributaries from the distal sesamoid bone.

The axial and abaxial parallel veins then united to form the *terminal vein* (Fig. 3, *g*). This vein ran proximally and caudally toward the abaxial aspect of the hoof. About two cm proximal to its origin from the parallel veins each terminal vein received a small ventral tributary (Fig. 3, g^{II}) that drained the axial aspect of the volar venous plexus (Fig. 9). About 1–2 cm proximal to its junction with this ventral tributary, the terminal vein had a dorsal branch that anastomosed with either the coronary vein or its tributaries (60%), or the subcoronary vein or its tributaries (40%) (Fig. 3, g^{I}).

After receiving the dorsal anastomotic branch, the terminal vein passed proximally on the medial aspect of the hoof cartilage. Between the distal part of the middle phalanx and the proximal third of the hoof cartilage, each terminal vein joined with the inner venous plexus (Fig. 3, *f*, f^{I}) to form the proper digital vein.

Branches of the inner venous plexus (Fig. 3, *f*) drained the volar venous plexus at the caudal-abaxial area of the sole and had some small abaxially directed branches through the hoof cartilage. These branches entered the axial aspect of the proximal half of the cartilage and joined the venous plexus of the wall. Occasionally one of the main branches of the plexus passed through the hoof cartilage along with these small branches.

The proximal branch that contributed to the formation of the inner venous plexus (Fig. 3, f^{I}) ran proximally and cranially and drained the deep bulbar (deep heel) region and angle of the wall (Fig. 9, f^{I}). This vein, which was situated entirely on the axial aspect of the hoof cartilage, eventually joined to the paracuneal vein (Fig. 9).

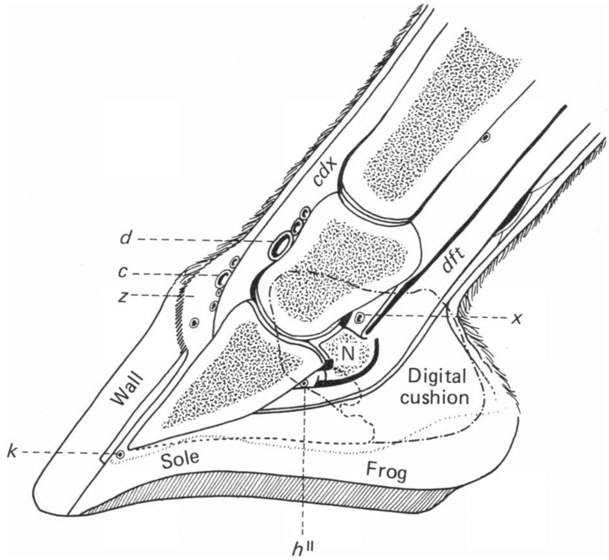

Fig. 5. Schematic diagram of sagittal section of horse hoof showing relative position of major veins. *c*, coronary vein; *d*, subcoronary vein; h^{II}, anastomosis between the axial parallel veins; *k*, circumflex vein; *x*, caudal anastomosis between both the proper digital veins; *z*, central mass of the coronary corium; *cdx*, common digital extensor tendon; *dft*, deep digital flexor tendon; *N*, distal sesamoid.

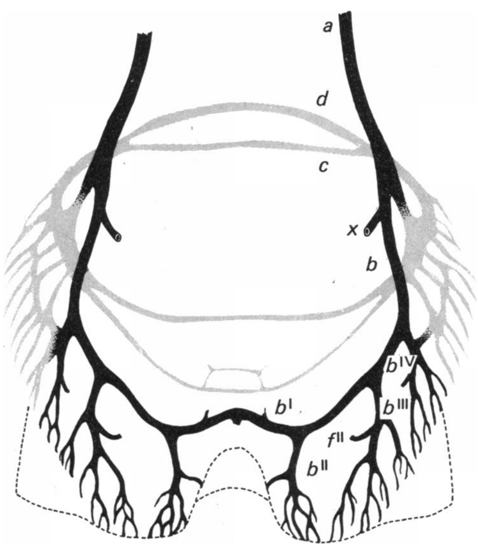

Fig. 6. Schematic diagram of the superficial veins of the caudal hoof (caudal view). *a*, proper digital vein; *b*, caudal hoof vein; b^{I}, first tributary of caudal hoof vein; b^{II}, second tributary of caudal hoof vein; b^{III}, third tributary of caudal hoof vein; b^{IV}, fourth tributary of caudal hoof vein; *c*, coronary vein; *d*, subcoronary vein; f^{II}, branches to the caudal hoof vein from the inner venous plexus on the caudal aspect of the hoof cartilage; *x*, caudal anastomosis between both the proper digital veins.

The inner venous plexus had direct connections to the branches of the superficially situated caudal hoof vein (Fig. 4, *b*) via large calibre veins. These connections occurred at the caudal border of the hoof cartilage (Fig. 6, f^{II}).

Close to the origin of the proper digital vein there was an anastomosis between the medial and lateral proper digital veins (Figs. 3–6, *x*). This anastomosis ran horizontally between the caudal transverse depression of the second phalanx and the distal sesamoid bone and its suspensory ligament (Fig. 5, *x*). This caudal anastomosis received branches from the digital cushion and the distal sesamoid bone.

The proper digital vein then ran proximally to the level of the coronary border where it became superficial and received venous blood from the superficial veins of the hoof.

(B) *Superficial veins*

Independent superficial vein. The independent superficial vein (Figs. 3, 4, 7, 9, *e*) drained into the abaxial aspect of each proper digital vein, near the junction with the coronary vein. It drained the caudalmost part of the coronary border near the heel region.

Coronary vein (*V. coronalis*). The coronary vein was the second major tributary from the hoof which drained into the proper digital vein (Figs. 3–7, *c*). The coronary veins of the lateral and medial proper digital veins were joined mid-sagittally, over the common digital extensor tendon, thus forming a semicircular anastomosis. The semicircular anastomosis of the coronary vein was in very close apposition with the coronary border mid-sagittally (Fig. 5, *c*). As the coronary vein passed caudally and abaxially toward the proper digital vein the distance between it and the coronary border increased. As a result of this, the length of the collecting veins that drained the coronary border into the coronary vein varied according to topographical location: the collecting veins in the toe region were shorter in comparison with those of the quarter and heel regions.

Each coronary vein received a horizontal tributary which ran abaxially from under the common digital extensor tendon of the mid-sagittal region (Figs. 3, 4, *d*). This vessel has not previously been named despite its large calibre. The name *V. subcoronalis* is suggested here as appropriate for this vessel. The subcoronary veins anastomosed with each other to form a venous arch, which was situated in proximity to the cranial transverse depression of the middle phalanx, between the middle phalanx caudally and common digital extensor tendon cranially (Fig. 5, *d*).

Caudal hoof vein. This vein was the most proximal tributary which drained into the proper digital vein (Figs. 3, 4, 6, *b*). In eight out of 20 hooves examined (40 %), the medial caudal hoof vein joined the medial proper digital vein 1–2 cm proximal to that point where the lateral caudal hoof vein joined the lateral proper digital vein. This vein drained the most superficial structures of the heel area by four principal tributaries:

(*a*) The distal tributary ran axially and horizontally at the caudal surface of the bulbar region. Mid-sagittally it anastomosed with the equivalent tributary of the other side to form the *interbulbar vein* (Fig. 6, b^{I}). Most commonly a single, large calibre vein with tributaries from the digital cushion drained into the interbulbar vein at its axial region, but it was not unusual to see two or three small veins from the digital cushion or interbulbar areas join the interbulbar vein.

(*b*) The second tributary joined the caudal hoof vein at the axial aspect of the bulb of the heel (Fig. 6, b^{II}): it drained the volar veins (Fig. 9, b^{II}).

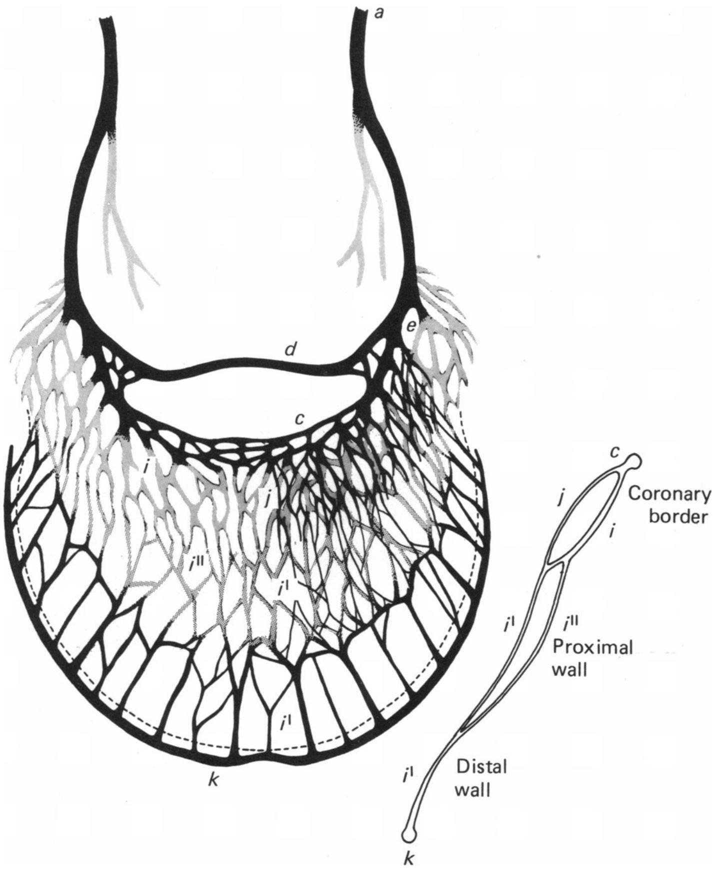

Fig. 7. (Left) Schematic diagram of veins of the coronary corium and the wall corium (dorsal view). (Right) Schematic diagram of the venous organisation of the wall and coronary corium (sagittal view), *a*, proper digital vein; *c*, coronary vein; *d*, subcoronary vein; *e*, independent superficial vein; *i*, long collecting vein; i^{I}, parietal collecting vein; i^{II}, deep collecting vein; *j*, short superficial collecting vein; *k*, circumflex vein.

(*c*) The third tributary joined the caudal hoof vein at the caudal border of the hoof cartilage (Fig. 6, b^{III}): it drained the superficial palmar bulbar area and originated from the volar veins (Fig. 9, b^{III}) and the inner venous plexus.

(*d*) The fourth, and most proximal, tributary joined the caudal hoof vein proximal to the hoof cartilage (Fig. 6, b^{IV}): it, like the third branch, originated from the volar veins (Fig. 9, b^{IV}) and inner venous plexus. It also drained the abaxial bulbar area and the angle of the hoof wall.

Intrinsic veins

The intrinsic veins of the hoof can be divided into three groups according to their location: (A) veins of the wall corium; (B) veins of the coronary corium; (C) veins of the frog and sole corium.

(A) *veins of the wall corium*

The venous network of the hoof wall corium could be divided into two regions: proximal and distal. The proximal region was that containing the parietal collecting venous plexus and the deep collecting veins of the proximal wall corium, while the

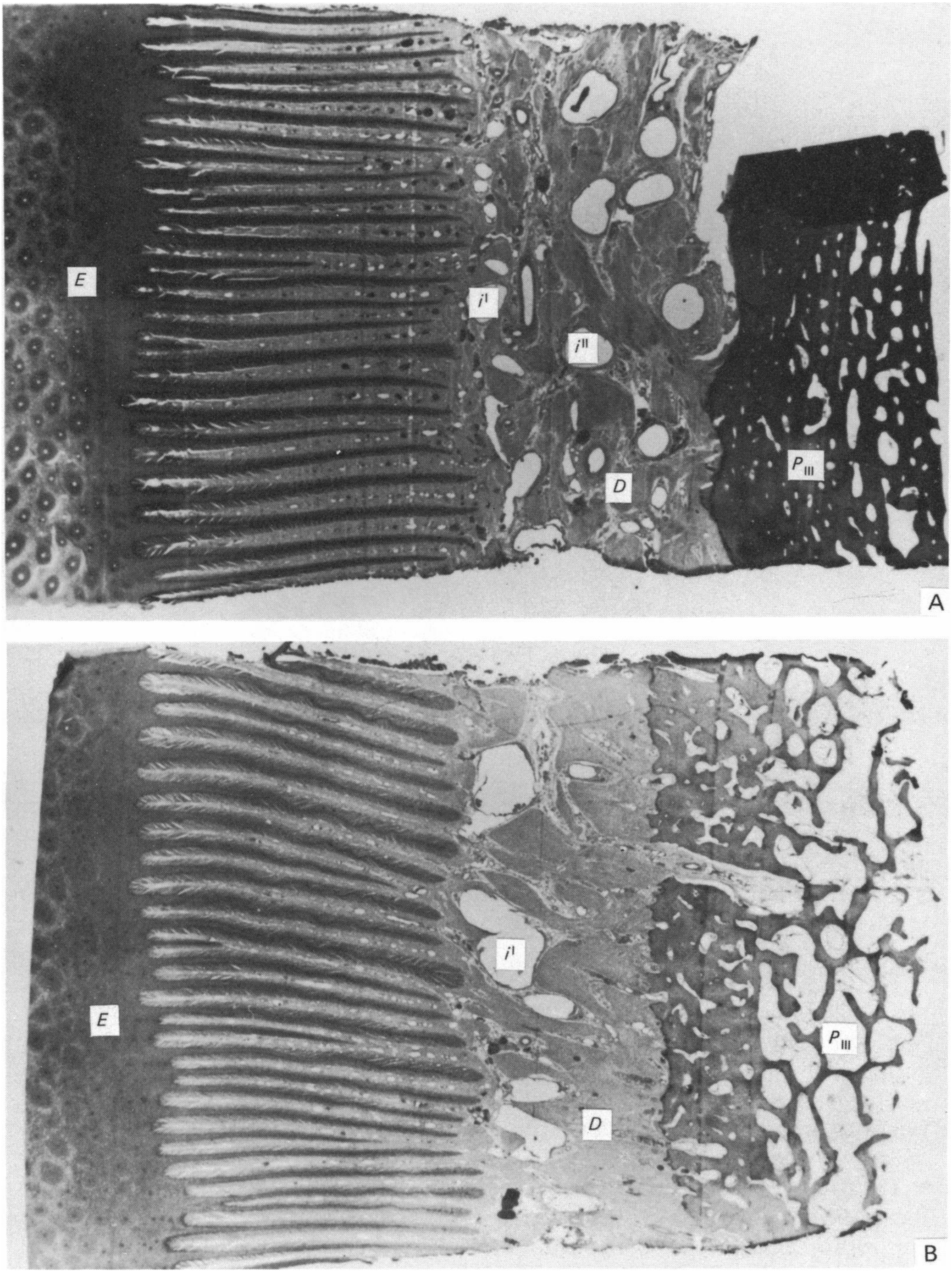

Fig. 8 (A–B). Photographs of histological sections (horizontal) through the wall corium, taken from areas A and C in Fig. 2, showing the large calibre intrinsic veins of the wall corium proper. (A) proximal wall; (B) distal wall. Haematoxylin and eosin stain. i^{I}, parietal collecting veins; i^{II}, deep collecting veins; *D*, dermis (corium); *E*, stratum medium; P_{III}, distal phalanx.

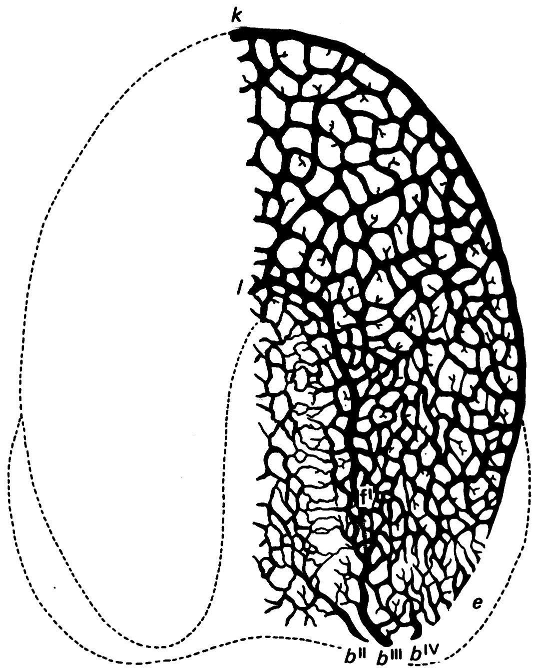

Fig. 9. Schematic diagram of the volar venous plexus of the distal (weight-bearing) surface. b^{II}, origin of the second tributary of caudal hoof vein; b^{III}, origin of the third tributary of caudal hoof vein; b^{IV}, origin of the fourth tributary of caudal hoof vein; *e*, origin of independent superficial vein; f^{I}, proximal sole vein from the inner venous plexus, which contributed to the paracuneal vein; *k*, circumflex vein; *l*, paracuneal vein.

distal region was formed by only the parietal collecting venous plexus of the distal wall corium (Fig. 8). The line of demarcation between these two regions was not sharp and regular. In most of the hooves examined, the line of demarcation was almost at the mid-dorsal region of the toe and extended caudolaterally and caudomedially to meet the coronary border at the heel. In some specimens the demarcation line was represented by a large calibre vein which ran horizontally across the hoof wall corium (Fig. 7).

The deep collecting veins were located deep in the proximal wall corium close to the distal phalanx (Fig. 7, i^{II}). These veins ran proximally from the middle of the wall corium to the lower half of the coronary corium, where they joined with the parietal collecting veins (Fig. 7, i^{I}) to form the long collecting veins (Fig. 7, *i*).

Deep collecting veins in the quarter area drained directly into the subcoronary vein and thus provided additional drainage to supplement that from similar tributaries to the coronary vein.

The parietal collecting veins were superficially situated in the wall corium close to the epidermis (Fig. 7, i^{I}). These veins ran proximally from the middle of the wall corium and anastomosed with one another to form a complex network. At the distal coronary corium the parietal collecting venous network became more deeply situated and joined the deep collecting veins (Fig. 7 i^{II}).

The lower part of the corium of the wall had only one superficially located venous supply, formed by the distal continuation of the parietal collecting veins (Figs. 7, 8B, i^{I}). There were no deep collecting veins in this region of the wall corium. The vessels of the parietal collecting venous plexus in this region had very few lateral branches and anastomoses. As a result, the parietal collecting veins ran distally, almost parallel to each other. At the junction with the deep collecting veins in mid-wall, the parietal collecting veins were thin but gradually became larger as the veins ran distally. All the parietal collecting veins joined the circumflex vein (Fig. 7, *k*).

The circumflex vein was a larger calibre vein of semicircular shape that passed along the distal circumference of the distal phalanx (Figs. 4, 5, 7, 9, *k*). Proximally, the circumflex vein received tributaries from the parietal collecting veins of the distal wall corium (Figs. 4, 7), and centrally it had numerous connections with the volar venous plexus (Fig. 9). Caudally the circumflex vein joined with many of the distal sole branches of the inner venous plexus of each side. Some branches from the circumflex vein ran ventral to the hoof cartilage and joined to the volar venous plexus, in close proximity to where the inner venous plexus joined the volar venous plexus. In some specimens the branches of the circumflex vein passed through the hoof cartilage to join the inner venous plexus.

(B) *veins of the coronary corium*

The coronary vein and the independent superficial vein received collecting veins (Fig. 7, *i,j*) from the coronary corium. The collecting veins were slanted cranio-distally (Fig. 7). Short superficial collecting veins (Fig. 7, *j*) ran proximally and interiorly to drain into the long collecting veins or directly to the coronary vein. These short superficial collecting veins received venous blood from the dermal papillae of the coronary border and from the parietal collecting veins of the wall corium (Fig. 7, i^{I}).

The long collecting veins ran proximally within the deep aspect of the coronary corium in very close apposition to the distal phalanx (Figs. 4, 7, *i*). These veins drained into the coronary or subcoronary veins.

In sagittal section the coronary corium had a typical D-shaped venous supply (Fig. 7). The long collecting veins (Fig. 7, *i*) represent the vertical bar of the D whereas the short superficial collecting venous network (Fig. 7, *j*) represents the curvature of the D. There were no veins in the central mass of the coronary corium (Fig. 5, *z*).

(C) *veins of the sole and frog corium*

The circumflex vein was a common channel for draining venous blood from the corium of both wall and sole. The circumflex vein received numerous tributaries from the sole venous plexus at the toe and quarter regions (Fig. 9).

The volar venous plexus was connected peripherally with the distal part of the superficial veins and centrally with the distal part of the deep veins.

There were two different venous plexuses within the corium of the sole, which together formed the sole venous plexus. The main venous plexus of the sole was formed by tributaries of the circumflex vein (Fig. 9), the branches from the inner venous plexus to the sole (Fig. 3, f^{I}), and by the ventral tributary of the terminal vein (Fig. 3, g^{II}). The proximal sole branch that contributed to the inner venous plexus (Figs. 3, 9, f^{I}), originated at the sole corium centrally from a prominent vein located in the paracuneal groove. This vein is called the *paracuneal vein* (Fig. 9, *l*). The paracuneal veins of opposite sides joined with each other at the tip of the paracuneal groove (Fig. 9).

The flat veins of this main sole plexus formed small multi-sided 'rings' from which fine calibre vessels abruptly emerged. In general, the fine vessels drained to the

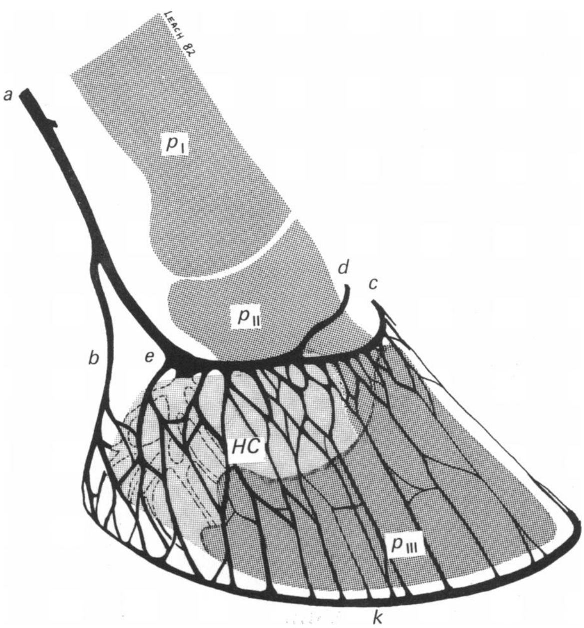

Fig. 10. Schematic illustration showing the major veins of the wall corium of horse hoof (lateral view). *a*, proper digital vein; *b*, caudal hoof vein; *c*, coronary vein; *d*, subcoronary vein; *e*, independent superficial vein; *k*, circumflex vein; *HC*, hoof cartilage; P_I, proximal phalanx; P_{II}, middle phalanx; P_{III}, distal phalanx.

middle of each side of these rings. The main sole plexus was situated deeply within the sole corium close to the distal phalanx.

The distal terminal portion of the last two tributaries of the caudal hoof vein, located at the lateral and caudal aspects of the bulb (Figs. 6, 9, b^{III}, b^{IV}), and some minor tributaries of the second tributary of the caudal hoof vein (Figs. 6, 9, b^{II}) received venous blood from a second venous plexus of interconnecting flat veins at the caudal portion of the sole. This caudal venous plexus of the sole overrode the main sole venous plexus, described above, for a distance of 1–3 cm. Several anastomoses occurred between these sole venous plexuses.

The interbulbar vein (Fig. 6, b^{IV}) received tributaries from the deep aspect of the frog. The second tributary of the caudal hoof vein (Figs. 6, 9, b^{II}) traversed the axial aspect of the bulb and received tributaries from the caudal and superficial aspects of the frog. These veins and their tributaries, together, formed the venous plexus of the frog.

The frog venous plexus had a few large calibre veins whose small branches anastomosed. This plexus was not as extensive as the venous plexuses of the sole but, instead, had numerous fine calibre vessels. The venous plexus of the frog communicated with the venous plexus of the sole through numerous branches. Tributaries from the frog and sole venous plexuses drained into the paracuneal vein (Fig. 9, *l*).

Summary of the veins of the wall (Fig. 10)

The lamellar corium and subjacent corium proper of the equine hoof wall were drained by tributaries to the following veins: (1) *coronary vein* (*V. coronalis*); (2) *independent superficial vein*; (3) proximal branch of the *caudal hoof vein*; (4) circum-

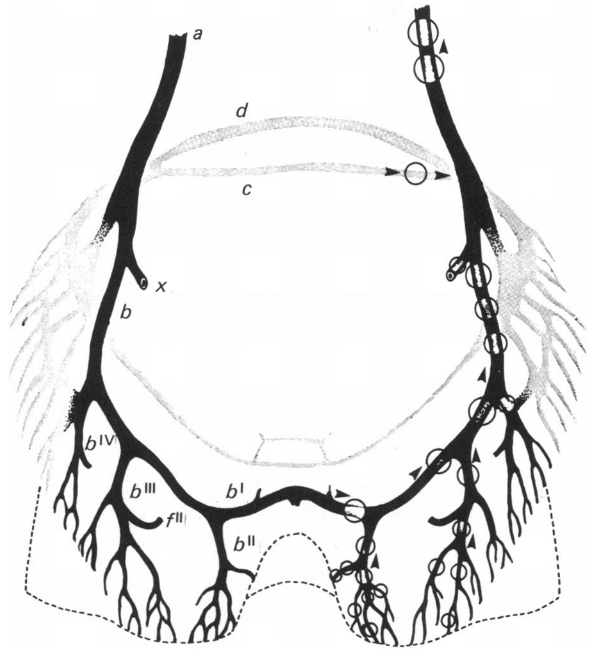

Fig. 11. Schematic illustration of the superficial extrinsic veins of the horse hoof, showing the location of the valves (caudal view). *a*, proper digital vein; *b*, caudal hoof vein; b^{I}, first tributary of caudal hoof vein; b^{II}, second tributary of caudal hoof vein; b^{III}, third tributary of caudal hoof vein; b^{IV}, fourth tributary of caudal hoof vein; *c*, coronary vein; *d*, subcoronary vein; f^{II}, branches to caudal hoof vein from the inner venous plexus on caudal aspect of hoof cartilage; *x*, caudal anastomosis between both the proper digital veins; arrowheads, direction of blood flow through the valves; circles, position of valves.

flex vein (*V. circumflexa*). These branches anastomosed to form the meshwork of veins of the hoof wall corium.

Veins of the wall corium of the toe and quarters were drained primarily to veins of the coronary venous plexus and to the circumflex vein. In the heel regions, this venous drainage network was supplemented by branches to the caudal hoof vein, independent superficial vein and anastomotic branches from the circumflex vein to the inner hoof plexus. Because of this supplementary venous return, the heel region was apparently better drained than other areas of the hoof wall.

The wall corium was drained distally by the circumflex vein.

Position of the valves of the hoof (Fig. 11)

Examination of the fully perfused plastic casts of 19 hoof specimens clearly indicated that valves were present primarily in the following two areas: (1) coronary and subcoronary veins and their tributaries within the coronary band region; (2) the caudal hoof vein and its tributaries on the palmar aspect of the hoof. A total of 155 valves was identified in the specimens examined.

Valves of the coronary and subcoronary veins and their tributaries

Valves were present only in the tributaries draining directly into the coronary and subcoronary veins of the toe and quarter regions. In 13 of 19 animals, valves were present in short superficial collecting veins, whereas in only 3 out of 19 they were observed in long collecting veins. Rarely, valves were found in the coronary or subcoronary veins.

Valves of the caudal hoof vein and its tributaries (Fig. 11)

Numerous valves were associated with this vein and its tributaries. A valve was routinely present at the terminal segment of each caudal hoof vein, and just distal to the junction of each of its four major tributaries. Within the main channel of the caudal hoof vein, other valves were occasionally present.

There was a preferential distribution of valves within the second tributary of the caudal hoof vein. Of the number of valves observed within the tributaries, 2% were found in the fourth tributary; 16% in the third tributary; and 82% in the second tributary.

Rarely, valves were identified in the following veins: (1) the independent superficial vein; (2) the caudal anastomoses between the medial and lateral proper digital veins; (3) the dorsal tributary of the terminal vein; (4) the vessels forming the inner venous plexus. Routinely, a valve was found in each proper digital vein just proximal to the caudal hoof vein. Other valves were incidentally observed in more proximal regions of the proper digital vein, but a detailed study of these valves was not made.

DISCUSSION

This study has described the organisation of the extrinsic and intrinsic veins of the equine forelimb hoof. The spatial position of the veins within the hoof corium, and the relation of veins to other structures such as the distal phalanx and hoof cartilage were also described.

There is no organisational difference between the venous plexus of the toe, quarter and heel regions. Areas such as the coronary corium, wall corium and corium of the sole and frog have different venous patterns: the corium adjacent to the areas of epidermal proliferation (sole, frog and coronary border) has an extensive plexus of large calibre veins (300–600 μm), whereas that associated with non-proliferating areas (wall corium) has a less extensive venous plexus.

Proximal versus distal wall corium

The venous organisation of the proximal half of the wall corium differs from the venous organisation of the distal half: the proximal half of the wall corium has two layers of venous plexuses, the exteriorly located parietal collecting venous plexus and the interiorly located deep collecting venous plexus; whereas the distal half of the wall corium has only one, exteriorly located, parietal collecting venous plexus.

Blood within the corium of the lamellae of the wall has several routes for venous drainage. Veins in the proximal part of the wall corium could easily evacuate venous blood by proximal flow through the parietal collecting venous plexus to the coronary or subcoronary veins which, in turn, drain directly to the proper digital veins.

The veins in the distal wall corium could drain through the parietal collecting venous plexus to the circumflex vein and then to a proper digital vein.

Coronary corium

The coronary corium has an extensive supply of large calibre veins, composed mainly of the coronary vein and its tributaries which connect directly to the digital veins. Except for the inner mass of the coronary border, there is an extensive capillary network of the coronary corium which drains directly and abruptly into the large calibre veins. Venous blood flow from the coronary border area of the heel is augmented by secondary drainage routes via the independent superficial vein, the caudal hoof vein and, indirectly, via connections to the inner venous plexus.

Drainage of venous blood from the coronary corium is achieved by proximal flow of venous blood through the plexus formed by the short superficial collecting veins. These veins drain blood into the coronary or subcoronary veins or into the independent superficial vein, which, in turn, drain into the proper digital veins.

Because the coronary and subcoronary veins form a semicircular ring and have connections with both medial and lateral proper digital veins, interruption or blockage of these veins at one place does not necessarily hamper the venous drainage from the coronary corium and from the proximal half of the wall corium.

Sole corium

The vessels of the sole venous plexus, including the more deeply situated secondary venous plexus of the caudal sole area, may potentially drain into one of the following vessels: (1) circumflex vein; (2) caudal hoof vein; (3) inner venous plexus of the proper digital vein, including branches going to the paracuneal vein. Peripheral flow within the venous plexus of the sole would drain blood into the circumflex vein. Centrally directed flow would direct venous blood into the paracuneal vein, to the sole vein and finally to the inner venous plexus. The venous blood could then be drained directly into the proper digital vein or indirectly to the proper digital vein via the independent superficial vein and caudal hoof veins. In addition, the sole venous blood may pass through the ventral tributary of the terminal vein.

Corium of frog

The venous system of the frog is intimately associated with, but quite distinct from that of the sole. This venous plexus consists of long slender interconnected veins of smaller diameter than that of the vessels of the sole venous plexus. The veins of the frog drain into the following vessels: (1) the paracuneal vein: (2) the second and third tributaries of the caudal hoof vein.

Comparison with previous work

The results of this paper generally agree with the exhaustive descriptions of the venous system given by Krüger (1934) and Schummer (1951), both of whom described the caudal hoof vein (*V. pulvinaris*) as a vein which drains the caudal part of the hoof and contributes to the volar venous plexus. This agrees with the findings of this paper. However, neither Krüger nor Schummer mentioned the four important tributaries, nor specified the location of valves of the caudal hoof vein. They also did not mention the existence of the independent superficial vein.

Schummer (1951) was the first to describe the division of the terminal vein into two parallel veins. Results of the present study also agree with Schummer's description and the name 'axial' and 'abaxial' parallel veins has been suggested for these vessels.

The existence of the paracuneal vein has not previously been described. Krüger (1934) described a prominent vein at the sulcus of the sole, which could perhaps be interpreted as the paracuneal vein. However, he described it as a distal continuation of the caudal hoof vein. In the present study, such a continuation with the caudal hoof vein was not found. Instead, it was found that the main tributary forming each paracuneal vein originated from the inner venous plexus formed by distal tributaries of the proper digital vein. The name 'paracuneal vein' is suggested here for this vessel.

According to Schummer (1951), both the deep and superficial collecting veins of the coronary band collect venous blood from deep and superficial regions of the coronary band, respectively. The present study does not support this interpretation. In this study it was found that only the superficial collecting veins drain into the coronary border area, whereas the deep collecting veins originate distally from the parietal collecting venous plexus of the wall.

Storch (1894) and Eberlein (1908) believed that there were no connections of the inner venous plexus with the superficial venous plexus of the wall through the hoof cartilage, whereas Krüger (1934) and Schummer (1951) described such connections. The observation of the present study agrees with the description of Krüger and Schummer.

Major connections between deep and superficial venous plexuses through the hoof cartilage were not found. However, several small diameter vessels connecting the deep and superficial venous plexuses were observed passing through the distal border of the hoof cartilage.

Possible reactions of the venous system during concussion

The hoof is subjected to a range of weight-bearing force, from that of standing to that imposed by the concussion of the limb as the animal is in a high speed gallop. These forces are believed to cause expansion of the frog and to deform all the soft tissue of the hoof, including the digital cushion, the hoof cartilage and the vascular systems. Because the soft tissues of the hoof are encased by the hard keratinised wall which cannot expand substantially (Fischerleitner, 1974), the internal deformation of the hoof may force evacuation of the venous blood from the hoof. The partial evacuation of the venous blood could probably be achieved very quickly. The multiple routes of drainage of the wall and sole venous plexuses, the absence of valves in the majority of veins of the hoof, the presence of valves in the proper digital veins and caudal hoof veins, and the presence of a double layer of venous plexuses at the junction of intrinsic and extrinsic veins are all probable mechanisms to evacuate the venous blood quickly and to distribute the pressure evenly. The absence of valves would help evacuation by allowing venous blood to take any convenient path. The presence of the valves in the caudal hoof veins and proper digital veins prevents the return of blood of the hoof and thereby helps to channel the venous blood into the systemic venous circulation.

SUMMARY

The extrinsic and intrinsic venous drainage of the equine hoof have previously been poorly described. There is also an absence of information about the venous organisation of both primary and secondary dermal lamellae of the hoof wall. The purpose of this study was to describe the normal venous pattern of the horse hoof, especially that associated with the dermal lamellae of the wall. The venous organisation of 46 pairs of hooves from clinically healthy horses was studied using standard plastic vascular corrosion casts and histological sections. A consistent pattern of venous organisation was observed in the toe, quarter and heel regions.

Veins in the proximal half of the wall corium form an exteriorly and an interiorly

located venous plexus, while in the distal wall corium only an exteriorly located venous plexus is present.

The wall corium of the toe and quarters is drained primarily by veins contributing to the coronary venous plexus and to the circumflex vein. In the heel regions this venous drainage network is supplemented by tributaries of the caudal hoof vein, independent superficial vein and anastomotic branches from the circumflex vein to the inner venous plexus. Because of this supplementary venous return the heel region is apparently better drained than other areas of the hoof wall. The wall corium is drained distally by the circumflex vein.

The coronary venous plexus is composed of an exteriorly situated short superficial collecting venous plexus and an interiorly situated deep collecting venous plexus. The short superficial collecting veins, which drain the proliferating zone of epidermis of the coronary border, connect directly to the coronary and subcoronary veins. The deep collecting veins drain only the proximal wall corium.

Most of the veins that drain the major portions of venous blood from the hoof are situated at the palmar aspect of the digit. These veins drain venous blood from the coronary venous plexus, the inner venous plexus and the superficial tributaries of the heel and bulb areas. The latter two venous systems receive venous blood from the sole and frog regions.

Most of the veins of the hoof are valveless, except for tributaries of the coronary and subcoronary veins, and the caudal hoof vein and its tributaries. It is suggested that the weight-bearing force is utilised for effective return of venous blood from the digit.

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